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The influence of substrate and cap layer on magnetic characteristics of some multilayers

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The influence of non-symmetrical boundary conditions, caused by different materials of the substrate and covering, on some properties of the systems consisting of magnetic layers separated by nonmagnetic spacer have been considered. Magnetic properties like spin wave patterns, FMR spectra, Curie temperature, magnetization and spin wave parameter B have been investigated for symmetrical and non-symmetrical structures like: Cu(111)/(Fe/Cu)$_n$/Fe/Cu/Si(111), vacuum/(Fe/Cu(111))$_n$/Fe/vacuum, vacuum/(Fe/Cu)$_n$/Si(111) and Cu/(Fe/Cu)$_n$/Fe/GaAs, vacuum/(Fe/Cu)$_n$/Fe/GaAs, where n is equal 1 or 2. Influence of roughness on selected characteristics of magnetic systems with non-symmetrical conditions on external surfaces has been also investigated.

Key words: *multilayers; FMR; Curie temperature; magnetisation; spin wave parameter*

1. Introduction

The structures consisting of magnetic layers separated by nonmagnetic spacer are interesting objects of research due to the their possible applications. Investigation of multilayers is always connected with the existence of a substrate determining crystal structure and anisotropy on the boundary surfaces. The other external surface should be protected by the cap layer. The process of preparation is the source of some roughness on the surfaces and interfaces of the structure; it modifies both interlayer exchange coupling and anisotropy parameters. Numerous papers have been devoted to the investigation of in what way cap layer thickness changes the Curie temperature [1–4] but only a few [5, 6] to the influence of external layers on the properties of multilayers. In the present paper, we consider the influence of substrate as well as cap of layers and their roughness on the basic magnetic properties of exchange coupled multilayers.

We assume the model according to which the interaction between magnetic layers separated by nonmagnetic metallic spacer can be described by the Heisenberg-type Hamiltonian:

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$$H = -\frac{1}{2}\sum_{\nu j,\nu' j'} J_{\nu j,\nu' j'} \mathbf{S}_{\nu j}\mathbf{S}_{\nu' j'} - g\mu_B H_{\text{eff}} \sum_{\nu j} S^z_{\nu j} - \frac{1}{2}\sum_{\nu j,\nu' j'} A_{\nu j,\nu' j'} S^z_{\nu j} S^z_{\nu' j'} \tag{1}$$

where ν denotes the number of monatomic planes and j the position of a lattice point in the plane, respectively.

The first sum in Eq. (1) is an exchange part of the Hamiltonian with the parameter $J_{\nu j,\nu' j'}$ equal to J inside magnetic layers and J_{12} standing for the interlayer exchange coupling parameter between the layers neighbouring the spacer. $A_{\nu j,\nu' j'}$ is the anisotropy parameter, being the sum of uniaxial volume anisotropy, and surface as well as interface anisotropy parameters, which are determined by the material of substrate and cap layer. H_{eff} denotes the sum of the external field oriented perpendicularly to the surface and the demagnetising field. The interlayer exchange coupling J_{12} in our paper has been derived based on the model proposed by Bruno and Chappert [7, 8], and can be modified similarly as in [9] by roughness described by solid-on-solid and discrete Gaussian models [10–12]. According to the relation proposed by Bruno [13] we took into account decreasing of anisotropy parameters for rough surfaces and interfaces in comparison to the ideal ones.

2. Results

In this section, we discuss numerical results for the Curie temperature, magnetisation, and spin waves parameter obtained for several systems using the Green function formalism [14]. First, we consider the influence of the substrate and cap layer materials (via surface anisotropy parameters) on the spin wave patterns and FMR spectra of magnetic trilayers. Figure 1a presents characteristics obtained for structures with the same material taken for the substrate, cap layer and spacer. We observe only one-peak FMR spectra. Changing the material and anisotropy parameters on both surfaces (Fig. 1b) causes a shift of the most intensive peak and appearance of an additional line in the FMR spectra. “Non-symmetrical” boundary conditions, related to different materials on external surfaces presented in Fig. 1c, give a small shift of the first mode line and a change of intensities of the others. In the presented example, only the latter configuration leads to a visible modification of spin wave patterns.

We have also examined the dependence of the Curie temperature of bi- and trilayers as a function of the spacer thickness. The results obtained are presented in Fig. 2. One can see from Fig. 2a that different materials on the surfaces of the multilayer are the source of reduction of the Curie temperature in comparison to the systems with the same materials on both external surfaces. Our results were obtained for a selected system, thus one should be very careful with generalizing them because shift of T_c depends on the number of magnetic layers, their thickness and anisotropy parameters on the surfaces and interfaces.

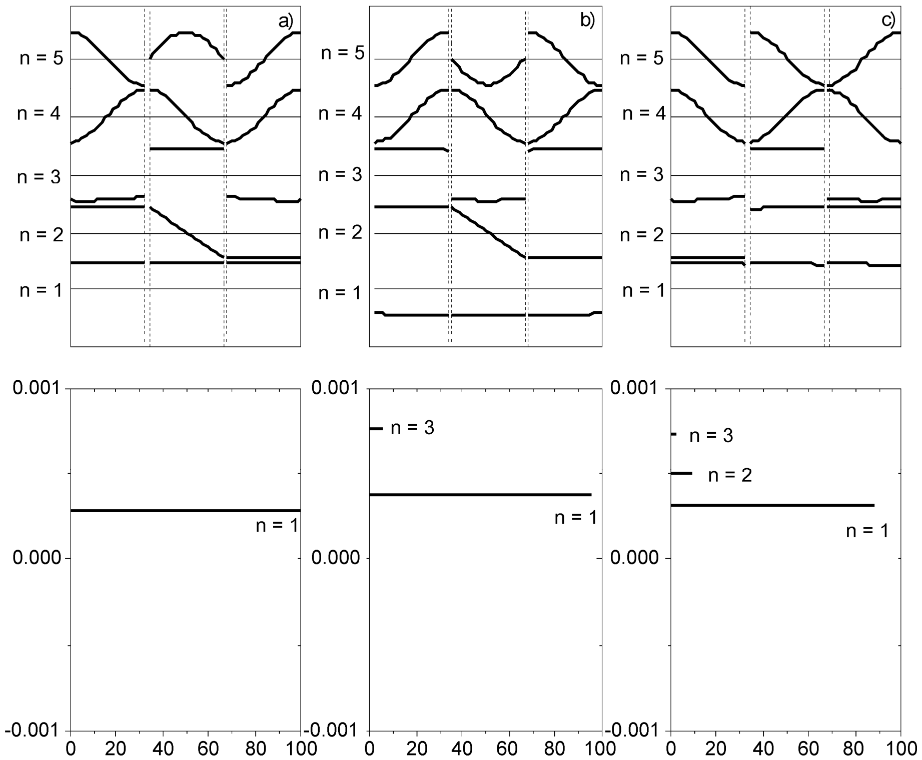

Fig. 1. Spin wave patterns (upper plots) and FMR spectra (bottom) for the systems:
a) Cu(111)/Fe/Cu/Fe/Cu/Fe/Cu/Si(111) [15, 16], b) vacuum/Fe/Cu/Fe/Cu/Fe/vacuum [17],
c) vacuum/Fe/Cu/Fe/Cu/Fe/Cu/Si(111). The layers of Si do not give any contribution to the anisotropy parameters. The thickness of each magnetic layer is equal to 20 ML's (labelling of horizontal axis of upper plots is omitted). The thickness of each spacer equal to 3ML's; *n* corresponds to the successive number of the spin wave mode. The energy axis in FMR spectra is given in arbitrary units

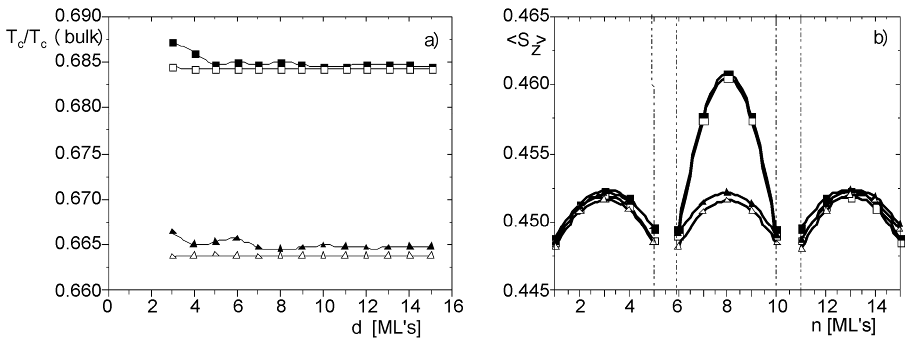

Fig. 2. The Curie temperature as a function of spacer thickness (a) and magnetisation profiles (b) for ■ – Cu/…./Cu/Si(111) (flat), □ – Cu/…./Cu/Si(111) (rough), ▲ – vacuum/…./Cu/Si(111) (flat) and △ – vacuum/…./Cu/Si(111) (rough), where rough or flat in brackets denotes degrees of surface roughness. Thickness of each magnetic layer is equal to 5 MLs and the spacer – 3 ML's. The structure between the slashes /…/ is Fe/Cu/Fe/Cu/Fe. The width of the "gap" is not related to the spacer thickness

Figure 2b shows magnetisation profiles for the same systems as in Fig. 2a. In this case, modification of magnetisation in an n-th monolayer of magnetic layers by changing the boundary surface anisotropies is especially visible in the middle of the structure. For the system with "non-symmetric" boundary condition, the magnetisation is significantly smaller in comparison to the system with the same material on both surfaces. The magnetisation inside the external magnetic layers is only slightly modified, a similar behaviour is observed in magnetic bilayers. The results presented in Fig. 2b indicate that changes in magnetisation distribution caused by the change of boundary conditions are too small to expect their experimental verification.

This behaviour of the Curie temperature and magnetisation is observed for both flat and rough surfaces and interfaces as we can see from the comparison of the characteristics with open symbols in Fig. 2 to those with filled symbols. The shift of respective curves is more significant for different systems than for the same ones but with different degrees of roughness.

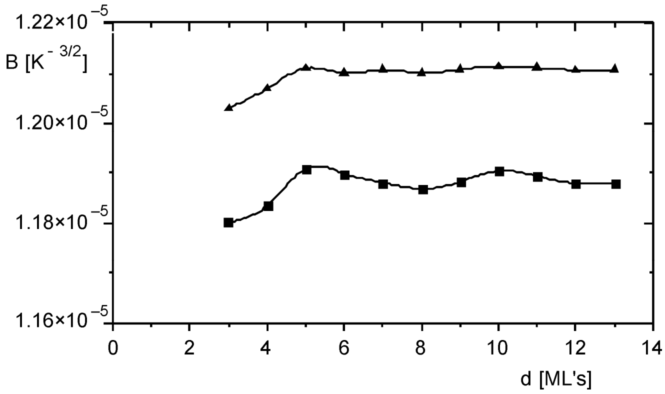

Fig. 3. The influence of spacer thickness on spin wave stiffness parameter for:
■ – Cu(111)/Fe/Cu/Fe/Cu/Fe/Cu/Si(111) and ▲ – vacuum/Fe/Cu/Fe/Cu/Fe/Cu/Si(111).
The thickness of each spacer is equal to 3 ML's and of magnetic layers to 5 ML's

We obtained numerical results for the spin wave parameter B appearing in the Bloch law for two chosen structures: Cu(111)/Fe/Cu/Fe/Cu/Fe/Cu/Si(111) and vacuum/Fe/Cu/Fe/Cu/Fe/Cu/Si(111). Although the difference between the values of this parameter for the considered structures is not significant, both characteristics in Fig. 3 can be easily distinguished. As we expected, the B parameter is an oscillating and decreasing function of the spacer thickness similarly as the interlayer exchange parameter J_{12} [18].

3. Conclusions and final remarks

Results presented in this paper can be approximately compared to the experimental results for the Curie temperature [19] and for spin wave parameter [20, 21], respectively. The order of magnitude for both cases is the same but a more exact comparison requires experimental investigation of the considerd systems. As we have shown, the influence of the roughness of surfaces and interfaces on the considered characteristics is less pronounced than the influence of anisotropy parameters in the border layers. We expect that it is possible to observe a visible experimental effect of the influence of diversity of substrate and cap layers on the properties of multilayered magnetic structures.

Acknowledgements

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